Initial Temperature Effects on Shock-Driven Power Supplies

***by* R. E. Setchell, S. T. Montgomery, M. U. Anderson, and D. E. Cox**

Motivation—Shock-induced depoling of the lead zirconate/titanate ferroelectric ceramic PZT 95/5-2Nb is utilized in pulsed power supplies. Detonation of a small explosive charge produces a shock wave propagating initially through alumina-filled epoxy (ALOX) encapsulant and subsequently through PZT 95/5-2Nb elements. Operational temperatures can vary from approximately -55 to 75 °C, and power supply output decreases substantially with increasing temperature over this range. A challenge for device design is to meet minimum output requirements at the highest temperatures while avoiding high-voltage breakdowns due to excess output at the lowest temperatures. Numerical simulations of this temperature dependence have been frustrated because the contributing roles of temperature effects in ALOX alone and in PZT 95/5-2Nb alone had not been carefully studied.

Accomplishment—Using a capability we established for conducting shock wave experiments over the temperature range of interest, we have investigated initial temperature effects on the shock properties of ALOX and PZT 95/5-2Nb separately. In PZT 95/5-2Nb, density changes over this temperature range are very small. Past experiments under short-circuit load conditions have shown that depoling currents are insensitive to initial temperature changes. Dielectric properties of ferroelectric ceramics, however, are known to be temperature dependent. When shock-induced depoling occurs under high field conditions, a portion of the depoling current is retained on the sample electrodes to account for sample capacitance. The retained current is "lost" in terms of delivery to an external circuit. Figure 1 shows the experimental configuration we have used to examine initial temperature effects on dielectric properties during shock propagation. Two small PZT elements are contained within a target assembly, and depoling of one element provides a current to charge a circuit consisting of the other PZT element in parallel with a load resistor. Figure 2 shows results obtained in experiments at different initial temperatures. These results quantify how the capacitance of PZT 95/5-2Nb increases significantly with increasing temperature. This effect alone will result in decreased power supply output at higher temperatures. Figure 3 shows the experimental configuration we have used to investigate initial temperature effects on shock properties in ALOX. Density changes in this material over this temperature range are also very small. Laser interferometry (VISAR) is used to record transmitted wave profiles in experiments conducted using fixed impact conditions and target dimensions. Figure 4 shows results obtained in experiments at different initial temperatures using a baseline ALOX containing 43% by volume alumina. Shock speeds and peak stresses (calculated from measured conditions) decrease significantly with increasing temperature. These effects, primarily due to temperature-sensitive epoxy properties, will also result in decreased output from power supplies at higher temperatures.

Significance—Temperature-dependent output is an important issue in the design of shock-driven power supplies. We are providing the first detailed insights into initial temperature effects on the separate shock properties of ALOX and PZT 95/5-2Nb. By incorporating realistic temperature dependencies in dynamic material models, numerical simulations of power supply operation will be able to consider temperature effects while examining design parameters and margins.

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Contact: David R. Sandison, Radiation & Nanosciences, Dept. 1110
Phone: (505) 844-9644, Fax: (505) 844-1197, E-mail: drsandi@sandia.gov

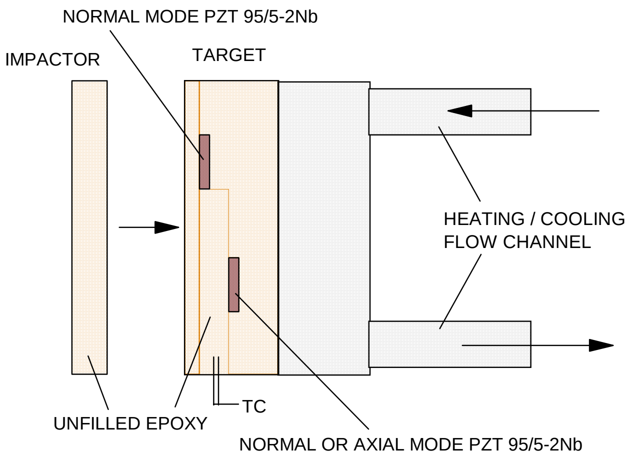

Figure 1. Configuration used for gas-gun experiments to investigate initial temperature effects on the dielectric properties of PZT 95/5-2Nb. Target temperatures are monitored using embedded thermocouples (indicated by "TC" in this figure).

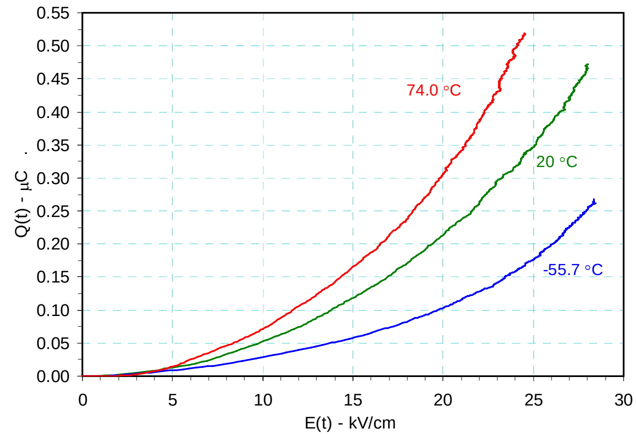

Figure 2. Charging of a poled PZT 95/5-2Nb sample in parallel with a load resistor by shock depoling of an adjacent PZT 95/5-2Nb sample. The displacement charge at a given time is plotted versus the electric field present at the same time. The time duration for the generation of each curve was 0.5 µs.

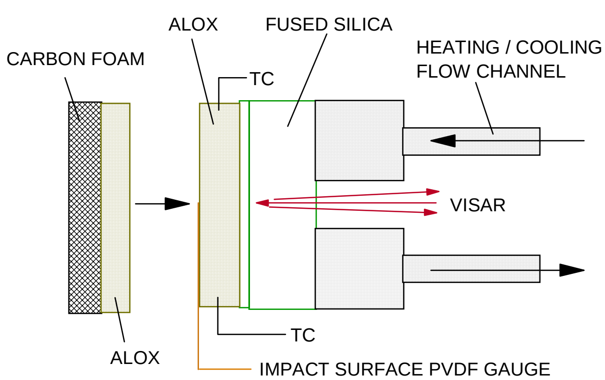

Figure 3. Configuration used for experiments to determine initial temperature effects on the shock compression and release properties of ALOX encapsulants.

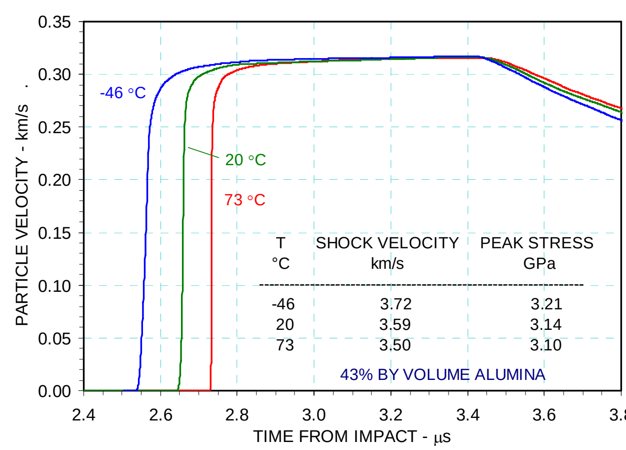

Figure 4. Transmitted wave profiles in baseline ALOX recorded in experiments conducted at different initial temperatures. Impact conditions and sample dimensions were the same in each experiment.